SAND2020-6808C

Facilitating International Cooperation through a Metrics Framework for Comparative Assessment of Nuclear Arms Control Verification Methods

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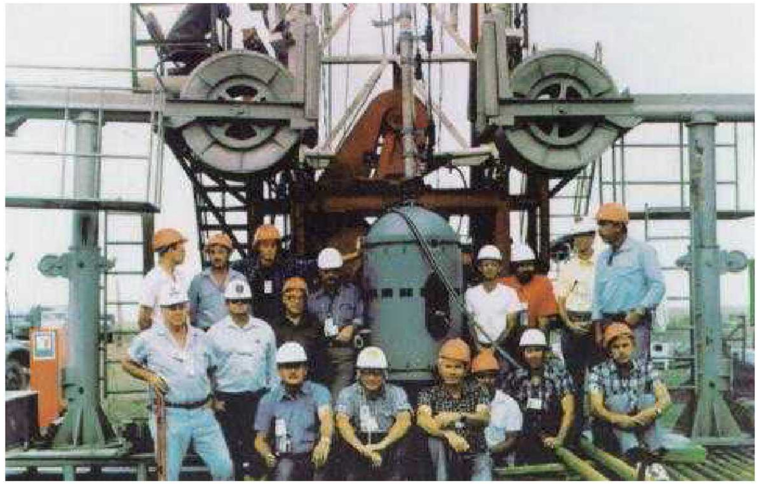
Throughout history, scientists and engineers have collaborated on the technical dimensions of arms control, including monitoring & verification.

Scientific experts and representatives participating in the Fifth Session of the Ad Hoc Group of Scientific Experts, held in Geneva, February-March 1978. Photo credit: ctbto.org



Joint Verification Experiment team, including specialists from USSR and US, at the Semipalatinsk Test Site, August 1988. Photo credit: lab2lab.stanford.edu

U.S. inspections begin under the INF Treaty, Saryozek, USSR, 1988. Photo credit: dtra.mil

Verification R&D lacks protocol- and technology-agnostic performance metrics for evaluating progress toward specific goals.

Metric: A system of measurement that includes the item being measured, the unit of measurement, and the value of the unit.

Standardized metrics are necessary to:

- Communicate progress towards incremental gains, a specified target, or a desired end state.
- Provide a consistent, transparent means by which to compare different options and approaches.
- Facilitate more effective communication and information sharing across diverse international communities of practice.

Metrics: MPH, MPG/MPGe, Torque, etc.

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Vs.

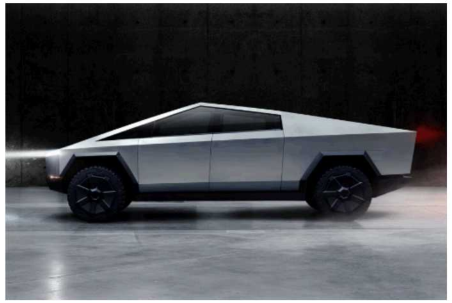


Photo credit: Tesla, Inc.

Metrics: MWe, $/kWh, burnup, etc.

Photo credit: Westinghouse Nuclear

Vs.

Photo credit: NuScale Power

Metrics: ??

Template Approach

Comparison of TAI against a recorded reference template; the template is generated through agreed-upon technical methods using a reference item that is agreed to be authentic

Vs.

Attribute Approach

Confirmation of intrinsic characteristics of a warhead through measurement of signatures, generally with information barriers to prevent release of sensitive information

Existing verification technical requirements, approaches, and technologies for nuclear arms control verification have largely been driven by treaties or specific technical agendas.

Implications:

- Development of new approaches/technologies is often derivative or ad-hoc, with limited continuity across efforts.
- Lack of agreed-upon metrics for communicating progress and building a narrative of continuity across disparate initiatives.
- Decisionmakers have limited information with which to compare/contrast the verification options available.

The metrics deficit will become more problematic as future treaties present more technically demanding verification challenges in areas that include:

- Establishing and confirming declaratory baselines.
- Confirming the presence of accountable items (to potentially include non-strategic weapons and warheads).
- Maintaining provenance of accountable items through transport, storage, dismantlement.
- Confirming final disposition of accountable items.
- Confirming that allowable deployed systems do not incorporate prohibited functionality.
- Protecting sensitive information during inspections.
- Confirming legitimate production operations do not create prohibited items or materials.
- Detect undeclared or clandestine items and activities.

Fortunately, existing initiatives and literature are suggestive of frameworks for deriving verification metrics.

The IAEA Safeguards system employs multiple metrics concepts (e.g. Significant Quantity, Detection Time, Detection Probability, False Alarm Probability, etc.).

Research suggests that a metrics-informed approach to verification R&D would include at least five steps:

1. Scenario definition.
2. Identification of verification objectives.
3. Functional mapping of verification technology and approaches to objectives.
4. Development and evaluation of metrics.
5. Convergence on a research agenda.

For international purposes, a workable approach to deriving metrics will need to be conceptually intuitive, scalable/adaptable across a range of potential agreements, and useful to both technical and policy communities.

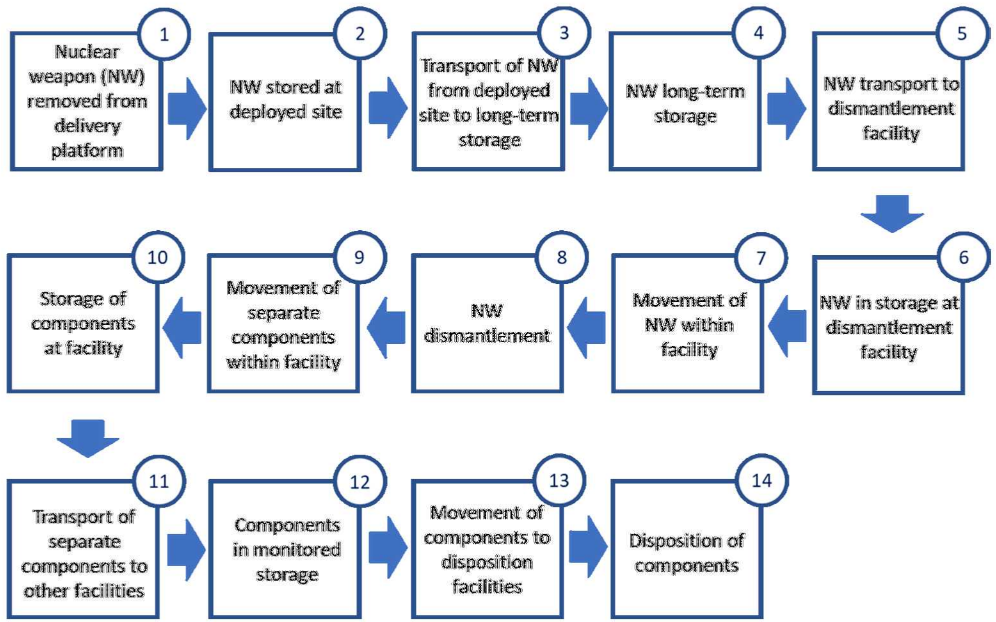
Useful conceptual points of departure for verification metrics:

Chen, C. et al. *Developing a System Evaluation Methodology for a Warhead Monitoring System*. Sandia National Laboratories, Report SAND2016-9371C. 2016.

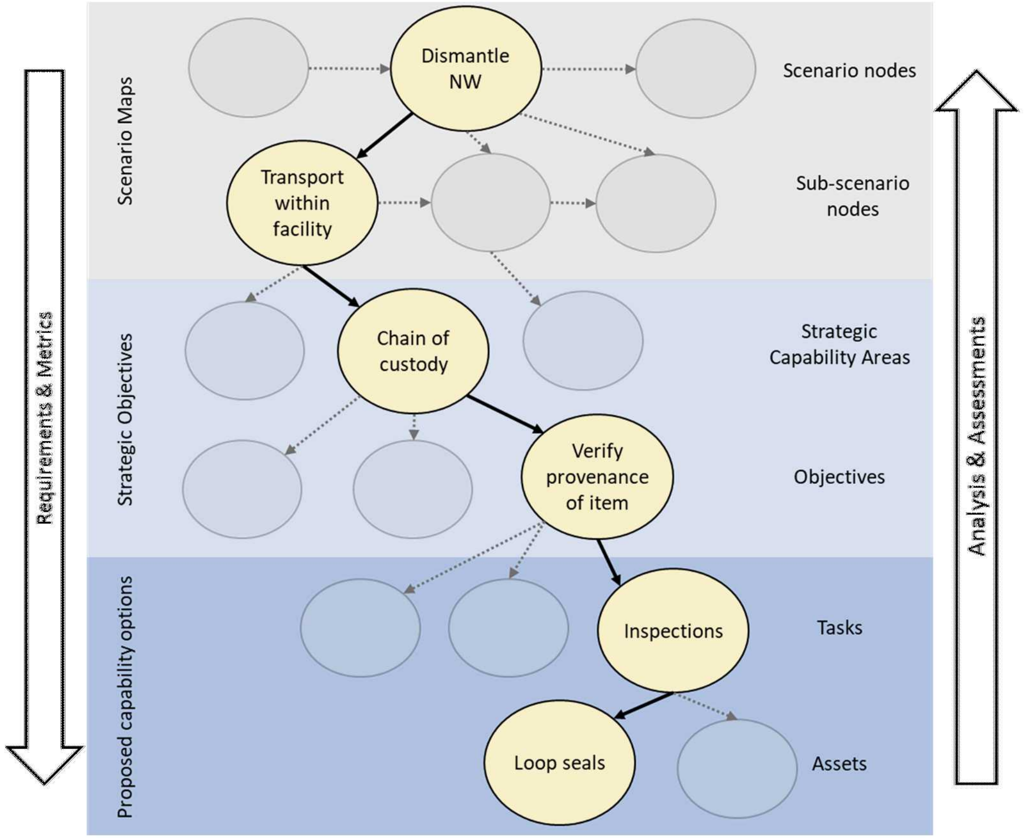
Department of Defense Science Board (DSB). *Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies*. Washington, DC: Defense Science Board. 2014.

International Partnership for Disarmament Verification (IPNDV). *Phase I Summary Report: Creating the Building Blocks for Future Nuclear Disarmament*. Washington, DC: Nuclear Threat Initiative. 2017.

Context matters; systematic and consistent scenario definition helps to clarify the specific verification context in which a metric might apply.



Adapted from IPNDV *Phase I Summary Report: Creating the Building Blocks for Future Nuclear Disarmament* (IPNDV 2017).



Adapted from DSB *Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies* (DSB 2014).

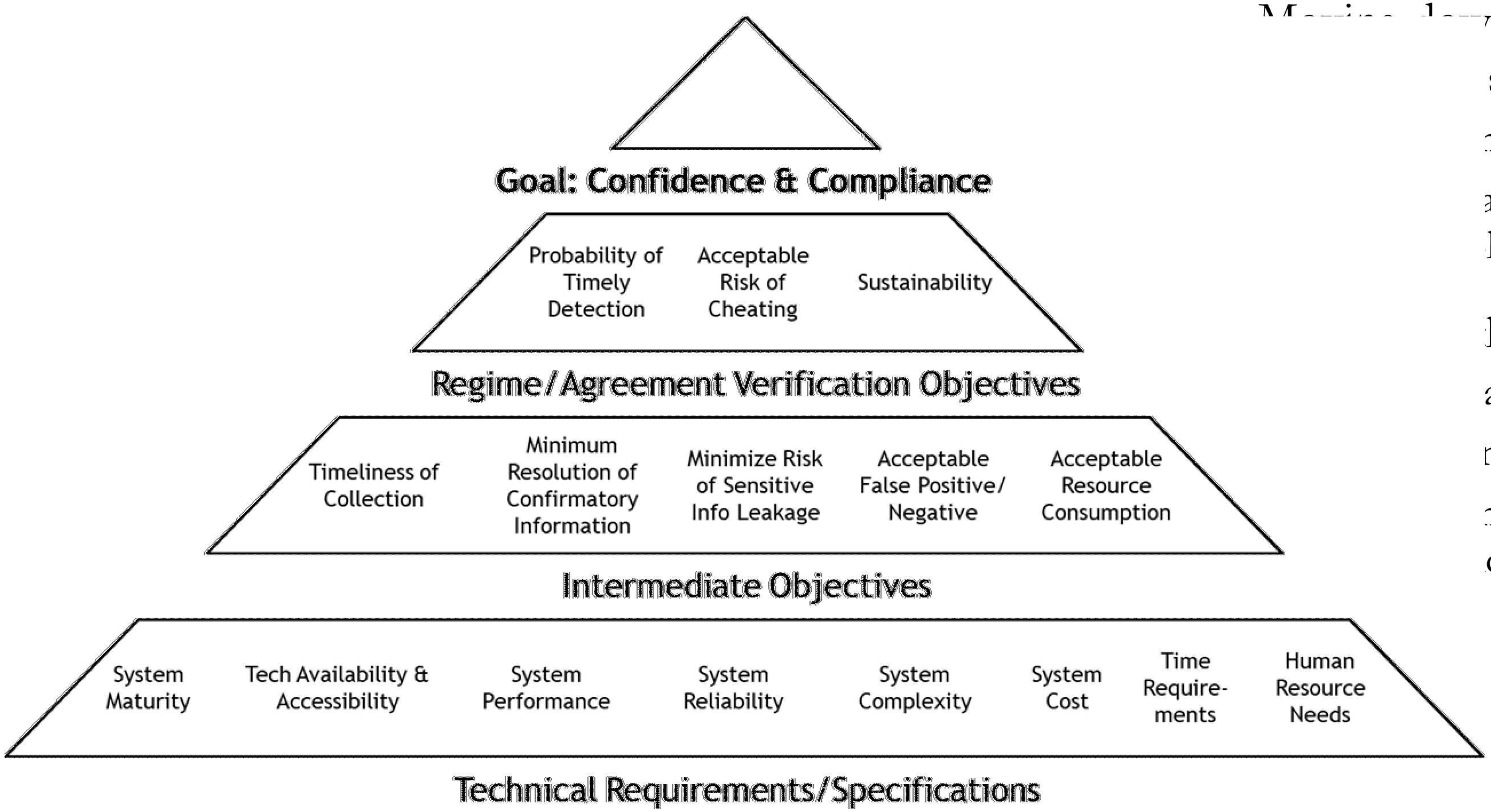
Metrics should ideally evaluate progress toward a set of consensus verification objectives.

The International Panel on Disarmament Verification (IPNDV) has identified high-level objectives that can serve as a starting point:

- **Effectiveness:** Verification must provide parties to a verification agreement with sufficient confidence of the compliance by other parties to that agreement.
- **Building Confidence:** A verification mechanism should help build confidence in the viability of the underlying agreement.
- **Nonproliferation:** Verification must not lead to the transfer of proliferation-sensitive knowledge.
- **Non-Interference:** The level of interference of verification activities is moderated by national interests, notably those related to security and safety.
- **Cost-efficiency:** Verification agreements must be cost/resource-effective.
- **Determinacy:** Verification must balance clarity, simplicity and flexibility.
- **Structure:** The role and position of national authorities in the context of verification must be well-established and balanced.

From IPNDV *Phase I Summary Report: Creating the Building Blocks for Future Nuclear Disarmament* (IPNDV 2017).

Metrics should ideally evaluate progress toward a set of consensus verification objectives; functional decomposition facilitates traceability between technology metrics and verification objectives.



n the hierarchy implies:

specificity/ narrowness of metrics

nents & targets derived from previous levels

al focus that can be decoupled (to a point) litical challenges

he hierarchy implies:

aggregation

ng influence of political considerations

nent for input from a broader set of ders beyond technical specialists

Verification presents unique and complex challenges, meriting innovative and multidisciplinary approaches to metrics development.

Performance evaluation of verification approaches and technologies requires measurement of concepts beyond just technical performance, including:

- Transparency
- Confidence in compliance based on individual and aggregated data points
- Confidence in absence of undeclared activity or technical capabilities
- Protection of sensitive information
- Deterrence value-added

These challenges suggest need to explore approaches and tools from other disciplines, including decision theory, economics, social science, and psychology.

Metrics development should be an iterative process; approaches will need to be revisited and revised as experienced is gained applying metrics in different contexts.

With objectives and metrics identified, communities of practice can converge on complementary research agendas.

The topic of metrics is complex enough that it can serve as the basis for a dedicated dialog; it might also be pursued in the context of existing dialogs and forums (e.g. IAEA or IPNDV).

Metrics also provide a basis for more informal cooperation; even if researchers are not working on the same initiative or program, the existence of commonly understood metrics will help ensure their work is in conversation and working toward common goals.

Fortunately, collaboration on metrics presents several intrinsic advantages:

- Ample precedent and starting points from existing initiatives and literature (no need to start from scratch).
- Technical-level metrics should be less politically contentious.
- Metrics, if carefully selected, can provide a tool that is robust across a broad range of future agreements and technical developments.

Even in times of uncertainty for arms control, international cooperation on verification metrics can serve to strengthen technical exchange among arms control communities of practice, building confidence and trust that might catalyze progress on existing agreements and even spark new initiatives.